KEITHLEY RADIATION MEASUREMENTS

Model 35080A

kVp Divider
Instruction Manual

Contains Operation and Maintenance Information for the Model 35080A kVp Divider

Manual No. 37648IM

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The Model 35080A kVp Divider

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Section 1
SPECIFICATIONS

Range: 50 - 150 kVp with the Wide Range Filter Pack (37617C).
Accuracy: ±2% of reading, exclusive of linearity, filtration, and gain effects.
Calibration: Internally-generated signal provides a calibration check.
Permitted Tube Current Range: 1 mA to 3000 mA, dependent on waveform and distance.
Response Time: 150 microseconds 10 - 90%.
Environment: Operating temperature 15° to 35° C; storage temperature -35° to 50° C. Relative humidity to 90%.
Orientation: The long axis of the Model 35080A kVp Divider is oriented perpendicular to the axis of the X-ray tube to eliminate heel effect.

Table 1-1. Permitted Tube Current Settings (less than ±1 kV effect).

	Single-phase half - wave	Single-phase full - wave	Three-phase
Minimum Tube Current (12" Source-to-Table)	1 mA	2 mA	4 mA
Maximum Tube Current (22" Source-to-Table)	750 mA	1500 mA	3000 mA
Factory calibration performed at 200 mA, 2.5 mm Al inherent filtration, 22 inches source-to-table. Six-point calibration check.			

Batteries: One Eveready 9 V alkaline type 522; life approximately 60 hours; BATTERY CHECK function connects battery to output terminals for voltage measurement.

Dimensions and Weight: 60 mm high x 210 mm wide x 90 mm deep (2-3/8 in. x 8-1/4 in. x 3-1/2 in.) Net Weight 0.68 kg (1-1/2 lb.)

Filter Packs: One Wide Range Filter Pack* (37617C) is provided for measurement from 50 to 150 kVp. A Test Pack (32863C), also included, provides verification of instrument accuracy. A K-edge Mammo Filter Pack (37355C)* and a Linear Mammo Filter Pack (37351C) are available as options for precision measurements from 22 to 40 kVp. A CT Filter Pack (33551C) is available as an option for CT system kVp measurements from 70 to 140 kV. A Mobile Filter Pack (37946C) is available for measurements on X-ray systems with kV waveforms above 1 kHz with substantial ripple.

Table 1-2. The Wide Range Filter Pack (37617C) Specifications.

Range: 50 to 150 kVp ***Sensitivity:*** 0.1 V / 10 kV ***Cal:*** 0.400 V ***Zero:*** 40 kV ***Cal:*** 80 kV ***Accuracy:*** ±2% exclusive of linearity and filtration effects.
Linearity and filtration effects can be corrected using curves from Section 4--OPERATING INSTRUCTIONS--of this Instruction Manual.

* *Patent numbers 4,843,619 and 4,916,727.*

Section 2
INTRODUCTION AND APPLICATIONS

The Model 35080A kVp Divider is an alternative to high-voltage divider tanks. It provides a safe, non-invasive, fast measurement of kVp without endangering personnel and/or equipment. Its use is primarily intended for X-ray machine service and calibration.

High-speed precision logarithmic circuitry allows for wide variations in mA and distance without a sacrifice of accuracy or response speed. The Model 35080A kVp Divider provides an analog output voltage proportional to the instantaneous voltage applied to the X-ray tube. When the Model 35080A kVp Divider is connected to a storage oscilloscope, the kV waveform may be viewed directly. If a digital display of the kVp value is desired, then the Model 35080A kVp Divider may be connected to the Keithley Model 35050A Dosimeter / kVp Readout.

One Wide Range Filter Pack (37617C) allows high-accuracy measurements from 50 to 150 kV. The Model 35080A kVp Divider is placed on the X-ray table with the filter pack in place. A storage oscilloscope is connected to the Model 35080A kVp Divider. The X-ray beam is collimated to the area of the filter pack. An exposure is made and the kV waveform is displayed on the storage oscilloscope. At no time are the high-voltage supply cables disturbed.

The Model 35080A kVp Divider is highly portable -- a contrast to bulky, heavy high-voltage divider tanks. The instrument is accurate to ±2%, exclusive of linearity and filtration effects.

The user should note, however, that as with an invasive divider, the accuracy of readings will depend on the accuracy of the oscilloscope or readout device used in the measurements.

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Section 3
THEORY OF OPERATION

3.1 INTRODUCTION

When used with the Wide Range Filter Pack (37617C) the Model 35080A kVp Divider produces an output voltage which closely follows the voltage applied to the X-ray tube. It does this with a 10-90% response time of 150 microseconds, so the waveform can be used not only for determining kVp, but for making precise time determinations and for diagnosing generator malfunctions.

3.2 MEASUREMENT THEORY

(Refer to Figures 3-1 and 3-2.) In this measurement scheme, two X-ray detectors are used. The X-ray beam passes through a relatively heavy filter prior to striking detector A, and through a lighter filter prior to striking detector B. The ratio of the currents (I/I) is transformed to a voltage by a custom-designed ratio module.

Typically, this ratio voltage increases as the voltage applied to the X-ray tube increases. The ratio voltage is virtually independent of the current applied to the X-ray tube and the distance to the X-ray tube.

3.3 WIDE RANGE FILTER PACK (37617C)

The Wide Range Filter Pack (37617C) is one of two standard filter packs supplied with the Model 35080A kVp Divider. This filter pack gives linear performance over a wide 50 - 150 kVp range. Detailed characteristics of the filter pack are given in Section 1--SPECIFICATIONS--and Section 4--OPERATING INSTRUCTIONS--of this manual.

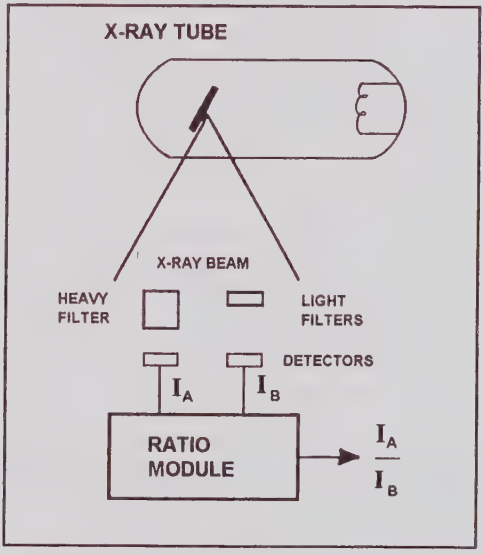


Figure 3-1. Simplified functional block diagram of the Model 35080A kVp Divider.

3.3 WIDE RANGE FILTER PACK (37617C) *(continued)*

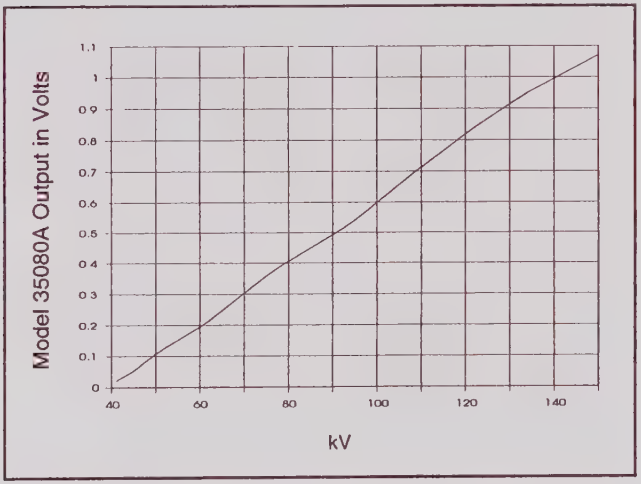


Figure 3-2. Output ratio plotted as a function of kV.

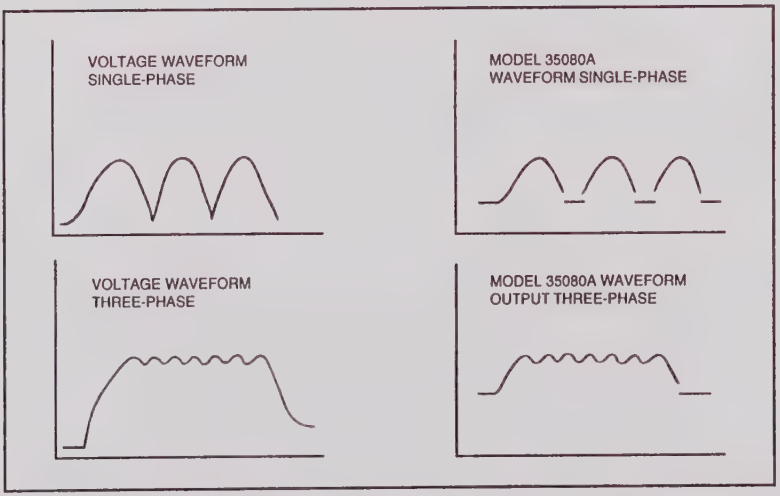


Figure 3-3. Output of the Model 35080A kVp Divider compared to voltage applied to X-ray tube.

3.4 OUTPUT

In the Model 35080A kVp Divider, the intensity ratio is taken with a high speed logarithmic ratio module. Thus, the output of the Model 35080A kVp Divider follows the kVp waveform applied to the X-ray tube within the linear range of the filter pack. The waveform differs from the waveform output of a resistive divider in that information below the kV baseline of the filter is not displayed (see Figure 3-3).

3.5 INTENSITY CUT-OFF

An examination of the Model 35080A kVp Divider waveforms in Figure 3-3 shows that as the potential of the X-ray beam waveform increases for the first time, the Model 35080A kVp Divider follows the signal as soon as it comes into the linear range of the filter pack. However, as the X-ray signal decays, the signal presented to the oscilloscope will suddenly switch to the filter pack's baseline. This effect is caused by a special circuit that prevents the presentation of a distorted signal to the oscilloscope. This circuit automatically resets about 10 seconds after an exposure is made.

3.6 INTERNAL CALIBRATION

In order to assure that the ratio circuit in the Model 35080A kVp Divider is stable, a "CAL" position is provided on the function switch. When the Model 35080A kVp Divider is switched into the "CAL" position, a signal ratio of 0.25 is electronically switched into the ratio circuit. This produces an output of 0.75 volts with no filter pack inserted or with the test pack inserted. This value should be within ±1% of 0.75 volts. When the Wide Range Filter Pack (37617C) is inserted, a CAL voltage of 0.40 volts ±1% is produced at the Model 35080A kVp Divider output. The CAL voltage is inscribed on each of the other filter packs. The value in kV is also given and this may be used to check the oscilloscope calibration.

3.6 INTERNAL CALIBRATION *(continued)*

NOTE

If the Model 35080A kVp Divider is exposed to an X-ray beam while the function switch is left in the "CAL" position, the resulting scope presentation will be badly distorted.

3.7 TEST PACK (32863C)

A Test Pack (32863C) is supplied with the instrument to provide a means for a second check of the Model 35080A kVp Divider's calibration. This pack has the same thickness of copper used to filter X-rays for both detectors. When the Test Pack is inserted into the Model 35080A kVp Divider, the ratio seen by the instrument (for adequately high intensities) is 1.0. The Model 35080A kVp Divider is factory- calibrated to produce 3.0 volts for a ratio of 1.0.

In theory, the 3-volt value is not a function of tube current, distance or kV; in order to have a standardized test, the 3-volt check should be run at 22 inches focal spot-to-table, at 200 mA and 100 kVp. Figure 3-4 shows typical waveforms for single-phase and three-phase exposures.

3.7 TEST PACK (32863C) *(continued)*

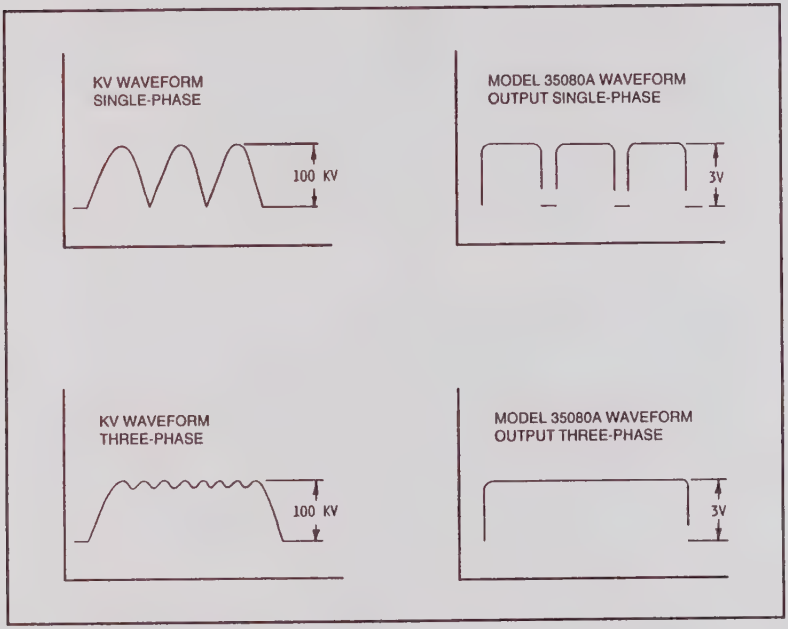


Figure 3-4. The Model 35080A kVp Divider single-phase and three-phase output with the Test Pack (32863C).

Section 4
OPERATING INSTRUCTIONS

Prior to taking measurements with the Model 35080A kVp Divider, it is suggested that the battery and internal calibration be checked.

4.1 BATTERY CHECK

Connect the output of the Model 35080A kVp Divider to a DVM (digital voltmeter). Place the Model 35080A kVp Divider function switch in the "BAT CHK" position. The battery should be replaced if the voltage is less than 7.0 volts as the remaining battery life is quite short. The battery must be replaced if the voltage is less than 6.25 volts as the instrument will not function properly when the voltage supply is below this minimum level.

4.2 INTERNAL CALIBRATION CHECK

Connect the output of the Model 35080A kVp Divider to a DVM with ±0.1% accuracy. Install the Test Pack (32863C) in the Model 35080A kVp Divider. Turn the function switch to the "CAL" position. After a short delay, a voltage of 0.750 ±1% will appear. This reading verifies the stability of the Model 35080A kVp Divider ratio electronics. A 1% error in the Model 35080A kVp Divider gain will cause a maximum kV reading error of 0.75% of reading. Refer to Section 9.3--Calibration--for detailed information on Calibration.

4.3 FILTER PACK SELECTION

One Wide Range Filter Pack (37617C) is provided as standard for the Model 35080A kVp Divider. See Sections 5, 6, 7, and 8 of this manual for use of the K-edge Mammo Filter Pack (37355C), the Linear Mammo Filter Pack (37351C), the CT Filter Pack (33551C), and the Mobile Filter Pack (37946C) with the Model 35080A kVp Divider. These are available as options from Keithley Instruments, Inc.

4.4 OSCILLOSCOPE ZERO AND OFFSETS

NOTE

It is assumed that the operator is familiar with the use of a storage oscilloscope. The following examples are for oscilloscopes with 8 major divisions for vertical scales and sensitivity selections of 0.1 V/div and 0.2 V/div. The selection of time scales or triggering are not discussed in this manual.

Figures 4-1a b show suggested oscilloscope settings for the 50 - 150 kV range using the Wide Range Filter Pack (37617C).

1. Insert the Wide Range Filter Pack (37617C) into the Model 35080A kVp Divider and connect the Model 35080A kVp Divider to the oscilloscope.

2. Set the oscilloscope gain to 0.1 V/div., DC Coupled. This setting corresponds to a 10 kV/div. sensitivity.

3. If making kV measurements from 50 to 120 kV, set the FUNCTION switch of the 35080A to the OFF position and adjust the oscilloscope vertical position control so that the oscilloscope trace coincides with the bottom horizontal line on the screen, which corresponds to 40 kV. Then set the FUNCTION switch of the Model 35080A kVp Divider to the "CAL" position and verify that after a delay of several seconds the trace on the oscilloscope coincides with middle horizontal line on the screen, which corresponds to 80 kV. When switching to the "RUN" position, a slight offset may be noted on the oscilloscope. Do NOT readjust the oscilloscope trace to compensate for this offset. Refer to Figure 4-1a.

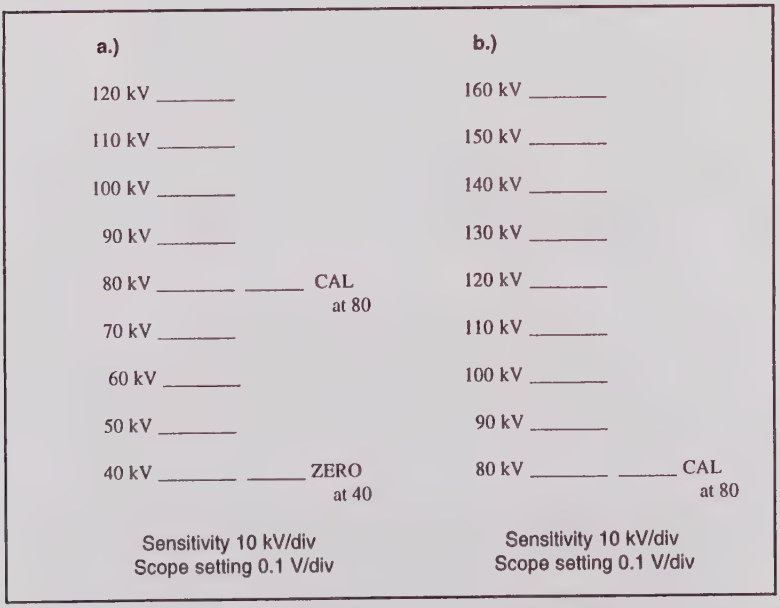
4. If making kV measurements from 120 to 150 kV, set the FUNCTION switch of the 35080A to the "CAL" position and adjust the oscilloscope vertical position control so that the oscilloscope trace coincides with the bottom line on the screen, which corresponds to 80 kV. Refer to Figure 4-1b.

4.4 OSCILLOSCOPE ZERO AND OFFSETS *(continued)*

NOTE

If the accuracy of the Model 35080A kVp Divider is in question, the output voltage may be checked with a ±0.1% DVM. The proper CAL voltage is on the filter pack label. The allowed tolerance is ±1%. A 1% error will cause at most a 0.75 % error in the kV reading.

Figure 4-1



Figures 4-1 a and b. Suggested oscilloscope settings for use with the Wide Range Filter Pack (37617C).

4.4 OSCILLOSCOPE ZERO AND OFFSETS *(continued)*

As an alternative to reading directly in kV, the output of the Model 35080A kVp Divider may be read directly in volts. The formula below is used to calculate the kV:

$$kV = \text{Model 35080A voltage} \times 100 + \text{ZERO kV}$$

Example: A peak voltage of 0.300 volts is read. The ZERO kV of the Wide Range Filter Pack (37617C) is 40 kV. Therefore:

$$kV = 0.300 \times 100 + 40$$

$$= 30 + 40$$

$$= 70 \text{ kV}$$

4.5 GEOMETRY OF SET-UP

The filter pack is aligned on the beam center, with the long axis of the Model 35080A kVp Divider perpendicular to the X-ray tube axis, and the beam normal to the table top (see Figure 4-2). The X-ray beam must be large enough to cover the active area of the filter pack. Distance is not critical, but a 22-inch distance from source to table-top is suggested.

The Model 35080A kVp Divider must be inverted for under-table X-ray head evaluation (refer to Figure 4-3). Again, the filter pack should be on beam center, perpendicular to the axis of the X-ray tube and the beam normal to the table. The beam area must be large enough to cover the active area of the filter pack.

In positioning the Model 35080A kVp Divider, the long axis of the instrument should be perpendicular to the X-ray tube axis to eliminate "heel effect." The beam must strike the filter pack side of the Model 35080A kVp Divider, the unit is designed to be turned over for under-table X-ray heads. In setting the X-ray generator, 200 mA at 22 inches is recommended, but the limits of operation allow higher or lower settings and distances. Refer to Section 1-- SPECIFICATIONS--for low current limits.

4.5 GEOMETRY OF SET-UP *(continued)*

After correctly positioning the Model 35080A kVp Divider, connect the oscilloscope, place the Model 35080A kVp Divider in the "RUN" mode and make an exposure.

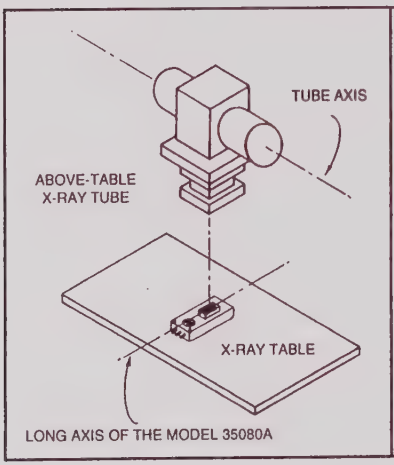


Figure 4-2. Geometry of set-up for above-table X-ray tube.

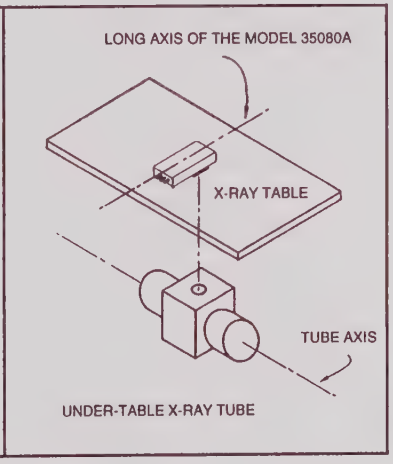


Figure 4-3. Geometry of set-up for below-table X-ray tube.

4.6 USE OF THE TEST PACK (32863C)

The Test Pack (32863C) is supplied with the instrument to provide a means for a second check of the Model 35080A kVp Divider's calibration. This pack has equal thickness of copper filters for both detectors. When the Test Pack is inserted into the Model 35080A kVp Divider, the ratio seen by the instrument (for adequately high intensities) is 1.0. The Model 35080A kVp Divider is factory-calibrated to produce 3.0 volts for a ratio of 1.0. In theory, the 3-volt value is not a function of tube current, distance or kV; in order to have a standardized test, however, the 3-volt check should be run at 22 inches focal spot-to-table, at 200 mA and 100 kVp. Refer to Figure 3-4 in Section 3--THEORY OF OPERATION--for typical waveforms from single-phase and three-phase exposures.

4.7 FILTRATION EFFECT CORRECTIONS

Corrections for filtration are made with the correction curves in Figure 4-4. Factory calibration of the 35080A is performed with 2.5 mm Al total filtration, so any other amount of filtration in the beam which is greater than or less than 2.5 mm Al will require some correction of the apparent reading.

Example: Suppose the Model 35080A kVp Divider reads 90 kV, using the Wide Range Filter Pack (37617C). The X-ray machine has 5.0 mm Al total filtration. The filtration effect curve for this filter pack indicates a filtration effect of 0.5 kV per mm Al at 90 kVp. To determine the actual reading, the filtration in the X-ray machine is subtracted from the standard calibration filtration (2.5 mm Al) and the resulting number is multiplied by the filtration effect: (2.5 - 5.0) x 0.5 = - 1.25 kV. The resulting number, - 1.25 kV, is the correction which is added to the apparent reading. Therefore, the actual reading is 90 kV + (-1.25 kV) = 88.75 kV.

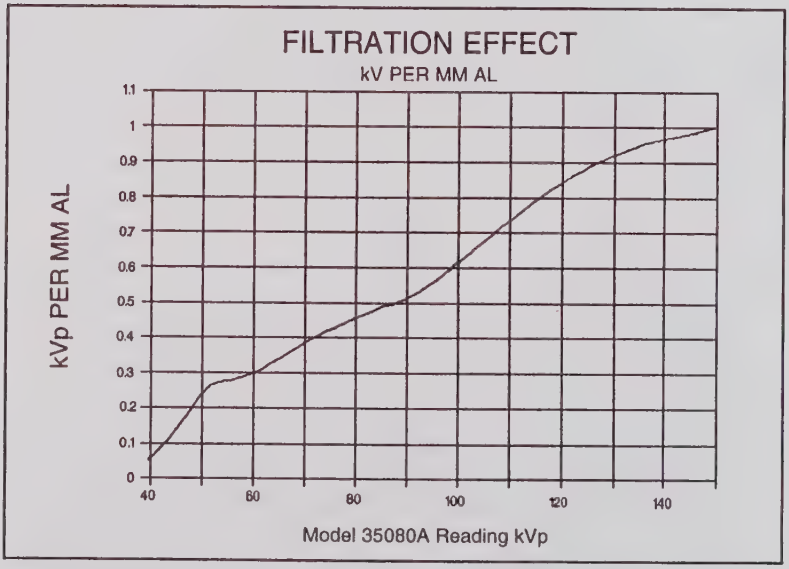


Figure 4-4. The Wide Range Filter Pack (37617C) Filtration Effect Correction Curve.

4.8 LINEARITY CORRECTIONS

Corrections for linearity in using the Wide Range Filter Pack (37617C) are made by taking the apparent output of the Model 35080A and adding (or subtracting) the value in kV shown on the following curve. For the greatest accuracy possible, readings should first be corrected for filtration before linearity corrections are made. For most applications, however, linearity corrections alone may be adequate, especially if the difference in total filtration from the calibration standard of 2.5 mm Al is small. See Section 4.7--Filtration Effect Corrections--for information about filtration correction.

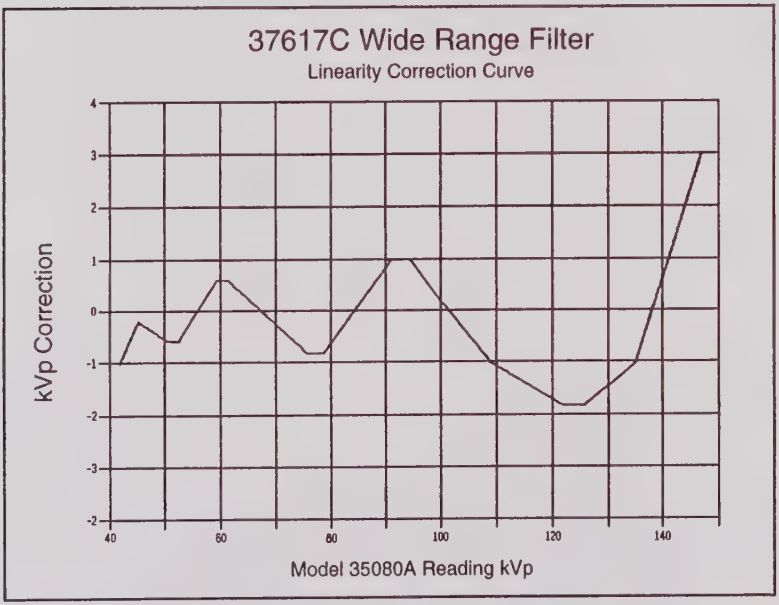


Figure 4-5. The Wide Range Filter Pack (37617C) Linearity Correction Curve. The kVp Correction Value read from the vertical scale should be added to the Model 35080A kVp Divider reading to produce the corrected kVp result.

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Section 5
CADMIUM K-EDGE MAMMO FILTER PACK OPTION (37355C)

5.1 SPECIFICATIONS

Intended Use: beryllium window, molybdenum anode mammographic generators
Range: 27.5 kVp to 29.5 kVp
Accuracy: ±0.5 kV
Sensitivity: 0.1 volt per kV
Zero: 27.0 kV
Cal: 0.75 volts
Minimum Anode Current: 50 mA
Target to Detector Distance: 12 in. (30.5 cm)
Effect of Molybdenum Filtration: negligible, 12 to 35 microns

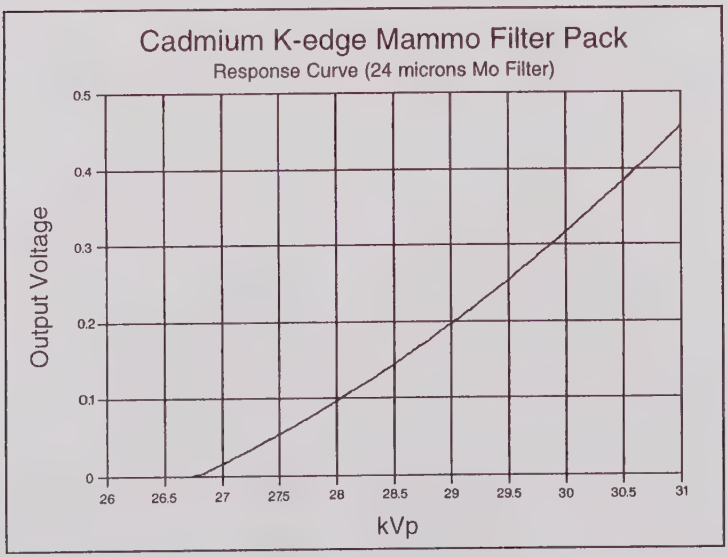

Figure 5-1. Response curve for the Cadmium K-edge Mammo Filter Pack (37355C).

5.2 INTRODUCTION

The Cadmium K-edge Mammo Filter Pack (37355C) provides a non-invasive way to make kVp measurements of mammographic X-ray generators. This filter pack uses the inherent stability of the Cadmium K-edge as an absolute reference for precision measurements between 27.5 and 29.5 kVp (for beryllium window, molybdenum anode mammographic generators with molybdenum filtration). When used in conjunction with the Linear Mammo Filter Pack (37351C), precision calibrations of ±1.0 kV accuracy can be performed from 22 to 40 kV.

5.3 THEORY OF OPERATION

The Cadmium K-edge Mammo Filter Pack contains two different filters side-by-side. One is constructed of cadmium, an element whose X-ray attenuation increases in a step-fashion at its K-edge (26.7 kV). The other filter is made of an element like aluminum which has no K-edge in the mammographic region. These two filters are selected to have identical attenuation characteristics for photon energies less than 26.7 kV.

The Model 35080A kVp Divider takes the ratio of the X-ray signals passing through the two filters. As long as the applied voltage to the X-ray generator is less than 26.7 kV, the output of the Model 35080A kVp Divider is constant (approximately 3 volts). When the applied voltage exceeds 26.7 kV, the ratio and thus the output voltage increases rapidly. The filters are carefully manufactured so that the voltage increases at 0.1 volt/kV above 27.0 kV. For molybdenum anode, beryllium window generators, there is very little effect on the calibration for changes in molybdenum filtration from 12 to 35 microns. As shown by Figure 5-2, the addition of aluminum filtration does influence the sensitivity. Adding 0.25 mm of aluminum can increase the Model 35080 kVp Divider's reading by up to 0.5 kVp.

5.3 THEORY OF OPERATION *(continued)*

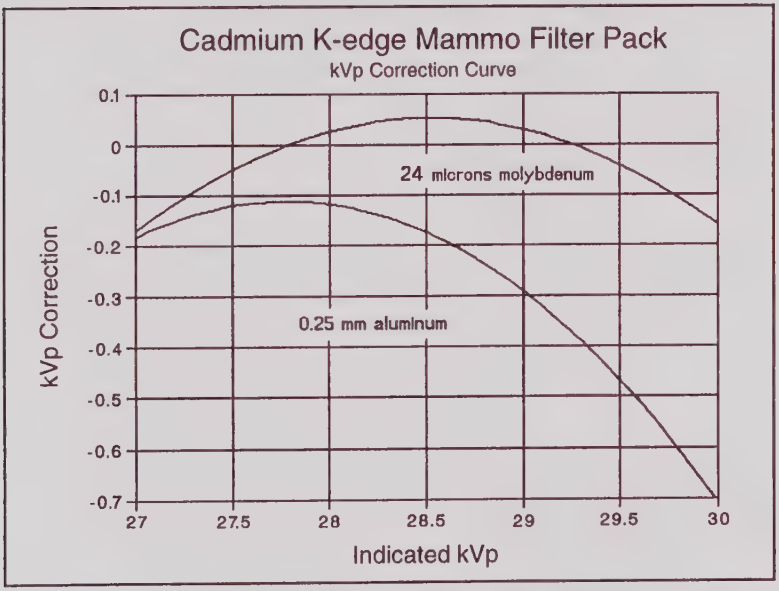

Figure 5-2. The kVp correction curves for the Cadmium K-edge Mammo Filter Pack (37355C).

5.4 OPERATING INSTRUCTIONS

1. **Measurement Set-up** - Place the Model 35080A kVp Divder in the X-ray beam on the compression paddle or other suitable support with the axis of the Model 35080A kVp Divider perpendicular to the axis of the X-ray tube. Raise the Model 35080A kVp Divider (with the Cadmium K-edge Mammo Filter Pack--37355C) as close as possible to the X-ray tube. The X-ray beam should cover the entire filter pack. (See Figure 5-3.)

5.4 OPERATING INSTRUCTIONS *(continued)*

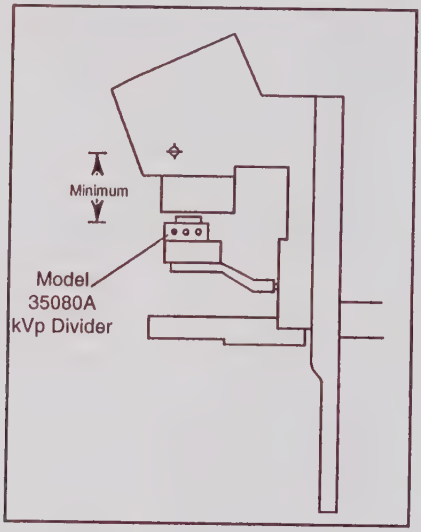

Figure 5-3. K-edge measurement set-up.

2. **Oscilloscope Set-up** - Connect the Model 35080A kVp Divider to the scope using a shielded cable and set the vertical sensitivity set to 0.5 volts per division. With the scope input in the GROUND position, adjust the vertical position control to place the trace on the bottom graticule line. Next, set the scope in single trace, storage mode and place the input selector switch in the DC position.

3. **25 kVp Measurement Procedure** - Set the X-ray generator for 25 kVp and 100 mA. If not available, use at least 50 mA and a minimum time of 50 msec or a mAs setting that provides these tube currents. Select the Mo (molybdenum) filter and make an exposure while adjusting the scope trigger level as necessary to get a stable trace. After measuring the peak voltage, record the value.

4. **26 kVp Measurement Procedure** - Set the generator for 26 kVp and make an exposure. Record this value also. (The two voltage values should be equal to within ±0.020V. If so, this will be your BASE VOLTAGE; if not, then repeat steps 3 and 4 at 24 and 25 kVp respectively.)

5.4 OPERATING INSTRUCTIONS *(continued)*

5. **29 kVp Measurement Procedure** - Set the generator for 29 kVp and make an exposure. (If this voltage is greater than the BASE VOLTAGE by 0.1 V to 0.25 V, record this new voltage value. If this voltage is greater than the BASE VOLTAGE by higher than 0.25 V, repeat this step at one kVp lower; on the other hand, if this voltage is not greater than the BASE VOLTAGE by 0.1 V, repeat this step at one kVp higher).

6. Subtract the BASE VOLTAGE from the voltage measured in step 5. Multiply this voltage by 10 and add 27.0 to determine the true kVp for this station.

7. Proceed to Section 6.5 (Linear Mammo Filter Pack Operating Instructions).

Example 1: DC Mammographic Generator

Figures 5-4 and 5-5 show the input and output waveform obtained from exposures taken at 24, 26, and 28 kVp respectively. The baseline value of 3.10 V can be seen from the lower pair of traces on Figure 5-5. The level measured on the upper trace is 3.20 V. The kVp corresponding to this trace is calculated as:

$$kVp = 27.0 + [10*(3.20-3.10)] = 28.0.$$

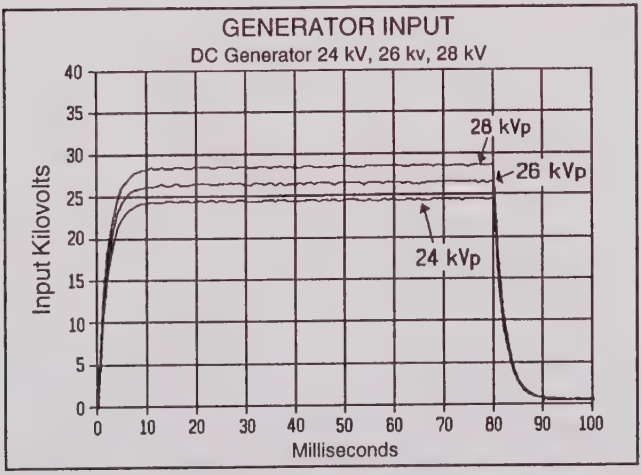

Figure 5-4. DC mammographic generator input waveforms.

5.4 OPERATING INSTRUCTIONS *(continued)*

Example 1: DC Mammographic Generator *(continued)*

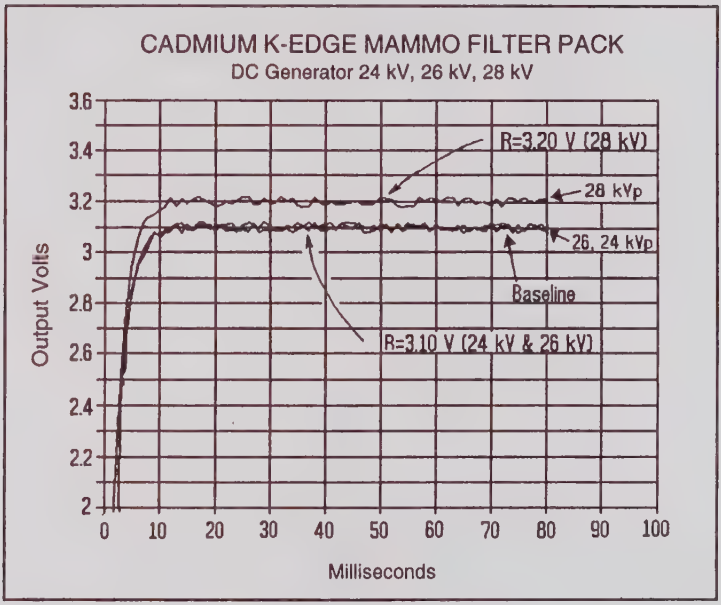

Figure 5-5. The Model 35080A kVp Divider output waveforms with the Cadmium K-edge Mammo Filter Pack (37355C) (DC mammographic generator).

5.4 OPERATING INSTRUCTIONS *(continued)*

Example 2: Single Phase Mammographic Generator

Figures 5-6 and 5-7 show the input and output waveform obtained from exposures taken at 28 kVp. Since it can be seen from Figure 5-6 that the kVp falls below the zero level of 27 kVp, the need to make several exposures while varying the kVp as in steps 3 and 4 is negated. The difference between the baseline and peak levels can be obtained from the single trace in Figure 5-7. This difference is measured to be 0.100 V, and thus the kVp is calculated as follows:

$$kVp = 27.0 + [10*0.100)] = 28.0.$$

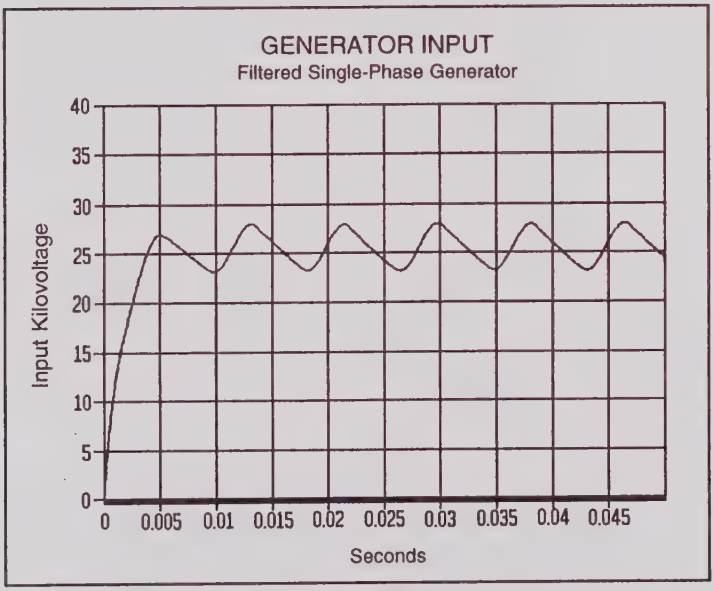

Figure 5-6. Single-phase mammographic generator input waveform.

5.4 OPERATING INSTRUCTIONS *(continued)*

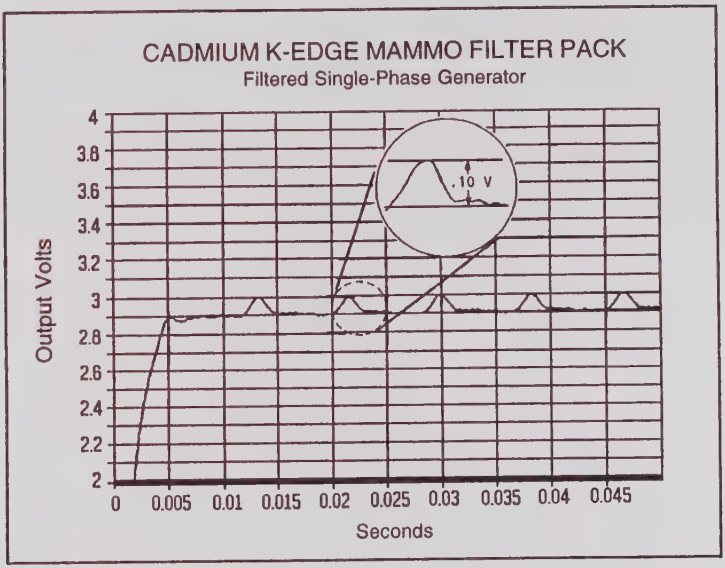

Figure 5-7. The Model 35080A kVp Divider output waveform with the Cadmium K-edge Mammo Filter Pack (37355C) (single-phase mammographic generator).

NOTE

When proceeding to Linear Measurement (Section 6.5--Operating Instructions) - Do not change the generator settings.

Section 6
LINEAR MAMMO FILTER PACK OPTION (37351C)

6.1 SPECIFICATIONS

Intended Use: beryllium window, molybdenum anode mammographic generators
Range: 22.0 kVp to 40.0 kVp
Accuracy: ±1.0 kV exclusive of filtration effects
Sensitivity: 0.01 volt per kV
Cal: 0.200 volts (20.0 kV)
Minimum Anode Current: 50 mA
Target to Detector Distance: 12 in. to 24 in. (30.5 to 61 cm)

6.2 INTRODUCTION

The Linear Mammo Filter Pack (37351C) provides a non-invasive way to make kVp measurements of mammographic X-ray generators. This filter pack features nearly perfect linearity for precision measurements between 22 and 40 kVp (for beryllium window, molybdenum anode mammographic generators with molybdenum filtration).

6.3 THEORY OF OPERATION

The Linear Mammo Filter Pack (37351C) is similar in construction to the Wide Range linear diagnostic filter pack except that the filter elements are much thinner. As expected in mammography, measurements are more sensitive to variations in added filtration than in the diagnostic range. Thus, the Linear Filter Pack (37351C) is normally used in conjunction with the K-edge Mammo Filter Pack (37355C). The K-edge Mammo Filter Pack (37355C) is used first to find a point between 27.5 kV and 29.5 kV very accurately. Then the Linear Mammo Filter Pack (37351C) measurement is made at the same point to determine the necessary correction to apply to the Linear Mammo Filter Pack (37351C) readings.

6.3 THEORY OF OPERATION *(continued)*

The reading from the Linear Mammo Filter Pack (37351C) is compared to that taken with the Cadmium K-edge Mammo Filter Pack (37355C) and a kV correction value for the Linear Mammo Filter Pack (37351C) is computed. This correction value is applied uniformly to all readings taken with the Linear. The K-edge measurement should be performed each time a generator is tested. Part of the correction factor for the Linear Mammo Filter Pack (37351C) is due to variations in tube filtration and part is due to positional dependence. Therefore when using the Linear Mammo Filter Pack (37351C), if the Model 35080A kVp Divider is moved, a new measurement at the K-edge comparison kVp point must be made with the Linear Mammo Filter Pack (37351C) and a new correction factor computed.

6.4 CORRECTIONS

If the amount of molybdenum filtration were known, the correction could be made with the correction curves in Figures 6-1 and 6-2. Figure 6-1 shows the correction required for total molybdenum filtration of 12 microns, 24 microns, and 35 microns (no correction is required for 24 microns). Figure 6-2 shows the effect of adding 0.25 mm Al to the 24 microns of molybdenum.

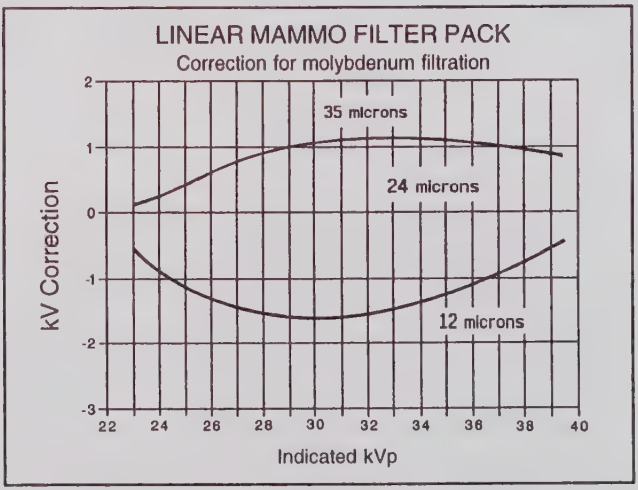

Figure 6-1. Correction curves for 12, 24, and 35 microns molybdenum filtrations.

6.4 CORRECTIONS *(continued)*

(Referring back to Figure 6-1,) a machine with 35 microns of molybdenum and a reading of 29.0, add 1.0 kV; the corrected reading is 30.0 kVp. For 12 microns and a reading of 28.0 kVp, subtract 1.5 kV for a corrected reading of 26.5 kV.

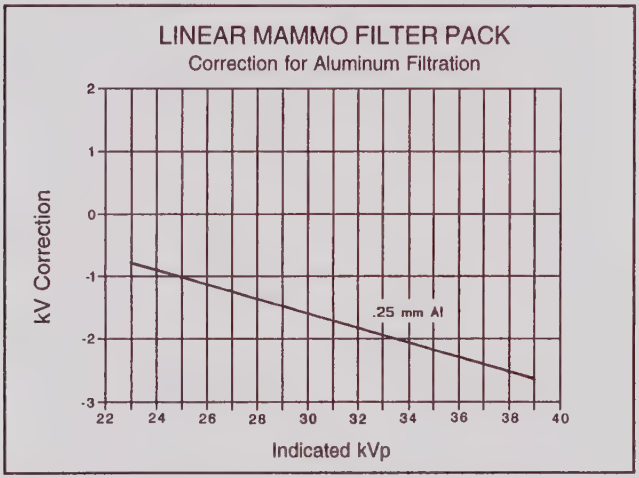

Figure 6-2. The correction curve that shows the effect of adding 0.25 mm Al (0.01 in. Al) to the 24 microns molybdenum filter. The aluminum makes the Linear Mammo Filter Pack (37351C) read high. To make corrections, subtract the kV correction from the indicated reading.

In most cases, amount of molybdenum filtration is unknown and the use of the Cadmium K-edge Mammo Filter Pack (37355C) for precise calibration of the generator at a kVp between 27.5 and 29.5 kV is required.

NOTE

See Appendix A Mammographic Measurements for more detailed instructions on the use of the K-edge and Linear Mammo Filter Packs (37355C and 37351C).

6.5 OPERATING INSTRUCTIONS

This procedure will normally follow that given in Section 5.4--Operating Instructions--where measurement with the Cadmium K-edge Mammo Filter Pack (37355C) ended.

1. **Measurement Set-up -** Replace the Cadmium K-edge Mammo Filter Pack (37355C) with the Linear Mammo Filter Pack (37351C). Reposition the Model 35080A kVp Divider to approximately 15 inches from the focal spot by lowering the compression paddle or other support device (see Figure 6-3).

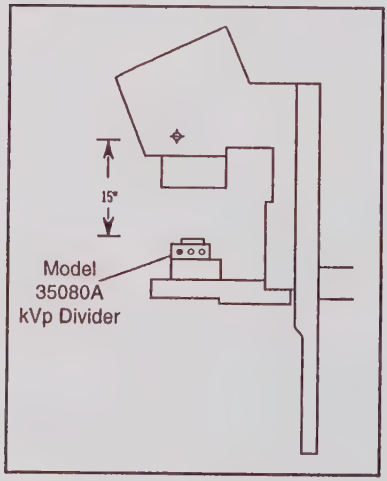

Figure 6-3. Linear measurement set-up.

2. Connect the Model 35080A kVp Divider output to either a storage oscilloscope or a peak-read-and-hold DMM. Set the oscilloscope to 0.05 volts division vertical gain and the input to DC Coupled, single trace storage mode.

6.5 OPERATING INSTRUCTIONS *(continued)*

NOTE

The Linear Mammo Filter Pack (37351C) may be used with a peak-read-and-hold DMM for the readout instead of or along side of the storage oscilloscope. The device is direct-reading in kVp. Merely multiply the display reading by 100. For example, a voltage of 0.375 is equivalent to 37.5 kV.

3. With the Linear Mammo Filter Pack (37351C) installed on the Model 35080A kVp Divider, move the switch to the "CAL" position. The voltage output should be 0.200 volts ±.003 volts (1% + 1 digit). Check CAL voltage with a digital voltmeter or an oscilloscope with at least 0.1% accuracy. This value corresponds to a kV reading of 20.0 kV and may be used to set-up the oscilloscope. The CAL function checks the gain of the Model 35080A kVp Divider. A 1% error in gain will result in a 1% error in the kVp reading (0.3 kV at 30 kV).

4. With the same generator settings used for K-edge measurement at 29 kVp (see Section 5.4--Operating Instructions), turn the Model 35080A kVp Divider to "OFF" and position the oscilloscope trace on the bottom line. Place the Model 35080A kVp Divider in the "CAL" position, and the trace will move to the middle line (20 kV). The oscilloscope with 8 major vertical positions is now set to indicate a range of 0 to 40 kV. Make an exposure and record this value separate from the K-edge reading made in Section 5.4--Operating Instructions, step 6.

5. Subtract this kVp voltage from the true K-edge kVp value (see Section 5.4--Operating Instructions). (This will be the CORRECTION VALUE applied to all kVp measurements made with the Linear Mammo Filter Pack--37351C.)

6.5 OPERATING INSTRUCTIONS *(continued)*

NOTE

The CORRECTION VALUE may be either negative or positive.

6. Measure other kVp values as desired. Record the LINEAR VOLTAGE, multiply by 100 and this will be your uncorrected LINEAR KVP. Lastly, add or subtract the CORRECTION VALUE and record the results. This now has the true kVp value for all kVp's measured.

NOTE

See Appendix A--MAMMOGRAPHIC MEASUREMENTS WITH THE MODEL 35080A kVp DIVIDER--for step by step instructions on using the Linear Mammo Filter Pack (37351C) in conjunction with the Cadmium K-edge Mammo Filter Pack (37355C).

Section 7
CT FILTER PACK OPTION (33551C)

7.1 SPECIFICATIONS

Range: 70 to 140 kV
Sensitivity: 0.1 V/10 kV
Cal: 0.644 volt
Zero: 60 kV
Cal: 124.4 kV
Linearity: less than 1 kV correction from 70 to 140 kV
Calibration Filtration: 2.5 mm Al
Filtration Effect: less than 1 kV per mm Al difference in filtration (from the 2.5 mm Al calibration standard) over the 70 to 140 kV range
Active Area: 40 mm x 6.5 mm
Minimum Anode Current: 25 mA at 25 inches

7.2 INTRODUCTION

The CT Filter Pack (33551C) provides a non-invasive way to make independent tests of the internal voltage divider of a CT system -- and a convenient and safe way to check tube voltage.

The actual kV waveform of the CT machine can be displayed on a storage oscilloscope. If the CT machine is a DC (continuous scan) unit, the proportional voltage can be read on a DMM.

These applications are made possible with the Keithley CT Filter Pack (33551C) in conjunction with the Model 35080A kVp Divider.

7.3 THEORY OF OPERATION

The Model 35080A kVp Divider contains a pair of solid-state detectors which when exposed to X-rays, send signals to a ratio module. The resulting ratio depends on the kV of the CT beam and the difference in thickness of filters placed between the detectors and the beam source.

The filters are carefully selected to give the best response curve possible over the kV range of CT interest (see Specifications).

The narrow dimensions of the CT Filter Pack's (33551C) detector area are suited to the beam area restrictions of CT applications.

7.4 OPERATING INSTRUCTIONS

1. Select 2.5 mm Al filtration and remove beam-restricting devices from the CT beam path on the CT machine. Open the beam width to 10 mm to cover the sensor area on the CT Filter Pack (33551C). Use the patient positioning laser to align the Model 35080A kVp Divider within the beam.

2. Connect the Model 35080A kVp Divider output to a storage oscilloscope.

3. Set the oscilloscope sensitivity to 0.1V/div., DC Coupled.

4. Put the Model 35080A kVp Divider into the "CAL" mode and verify its output is 0.644 volt ±1%.

5. Turn the Model 35080A kVp Divider OFF and position the oscilloscope trace to read 60 kV (the reference baseline on the oscilloscope which is added to the measured value).

6. Again, put the Model 35080A kVp Divider into the "CAL" mode and verify that the oscilloscope trace corresponds to 124.4 kV (±1 kV).

7. Place the tube head in its top position.

8. Switch the Model 35080A kVp Divider into the "RUN" mode and make the exposure.

7.5 CORRECTION OF READINGS

Filtration: (Refer to Figure 7-1.) No correction is needed for 2.5 mm Al. For a given kV reading: if the effective filtration of the CT beam is greater than 2.5 mm Al, subtract the difference (in mm) times the correction factor from the apparent reading; if the effective filtration is less than 2.5 mm Al, add the difference times the correction factor to the apparent reading.

Example 1: The kV reading is 100, and the total filtration of the beam is 3.5 mm Al. The difference between the effective and calibration filtration is 1 mm. This difference times the correction factor for 100 kV is 1 x 0.35 = 0.35 kV. Therefore the corrected kVp is calculated as, 100 kV - 0.35 kV = 99.65 kV.

Example 2: The kV reading is 80, and the total filtration is 2.0 mm Al. The difference between the effective and calibration filtration is 0.5 mm. The difference times the correction factor for 80 kV is 0.5 x 0.2 = 0.10 kV. Therefore, 80 kV is 0.5 x 0.2 = 0.10 kV. Therefore, 80 kV + 0.10 kV = 80.1 kV.

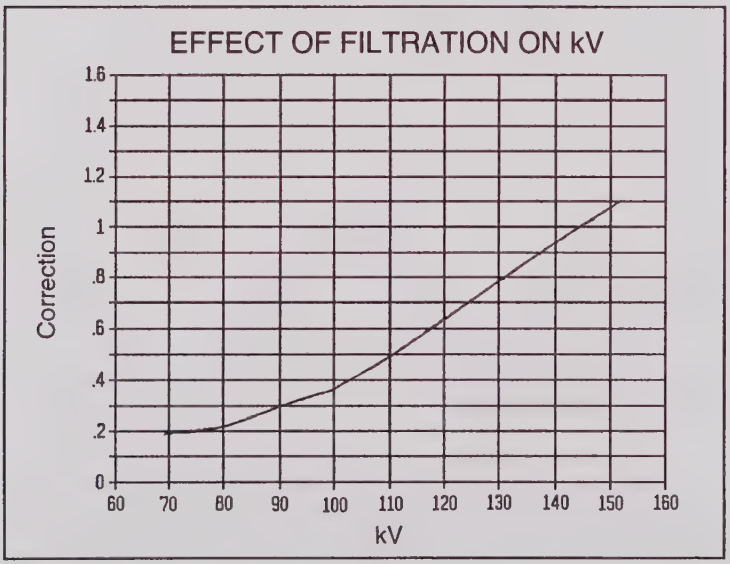

Figure 7-1. CT Filter Pack (33551C) Filtration Effect Correction Curve.

7.5 CORRECTION OF READINGS *(continued)*

Linearity: (Refer to Figure 7-2.) If a kV correction value (from the Y-axis) has a negative sign, then its magnitude is subtracted from the apparent reading shown on the X-axis. If a kV correction value is positive, then its magnitude is added to the apparent kV reading on the X-axis.

Example 1: If the apparent reading is 70 kV, the correction value is -1. Since the correction value has a negative sign, it is subtracted from the apparent reading. Therefore, 70 kV - 1 kV = 69 kV.

Example 2: If the apparent reading is 80 kV, the correction value is 0.9. Since the correction value has a positive sign, it is added to the apparent reading. Therefore, 80 kV + 0.9 kV = 80.9 kV.

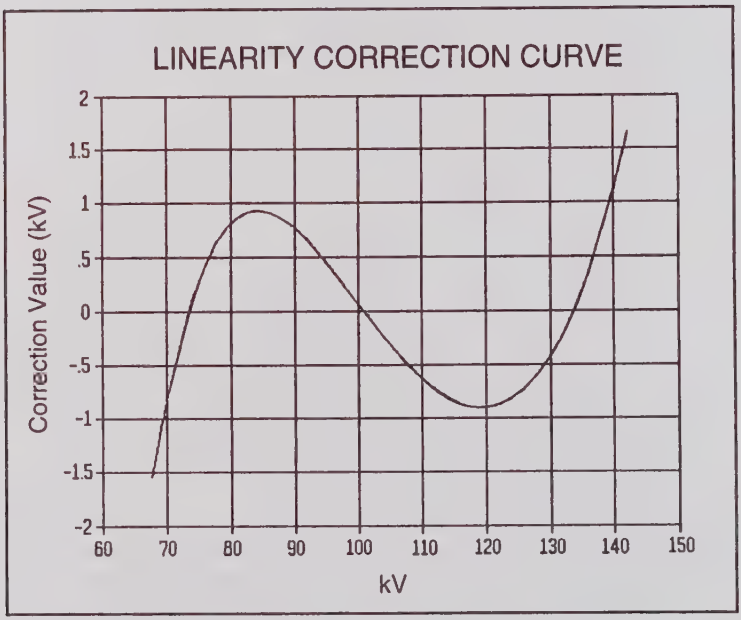

Figure 7-2. CT Filter Pack (33551C) Linearity Correction Curve.

Section 8
MOBILE FILTER PACK OPTION (37946C)

8.1 SPECIFICATIONS

Range: 50 to 135 kV
Sensitivity: 0.1 V/10 kV
Cal: 0.600 Volt
Zero: 40 kV
Cal: 100 kV
Calibration Filtration: 2.5 mm Al

8.2 INTRODUCTION

The Mobile Filter Pack (37946C) is a specialized filter pack designed primarily for use on mid to high-frequency generators (≥1kHz) with substantial kV ripple (≥10%). For single-phase and 3-phase generators, or other low-frequency generators (<1kHz), use of the Mobile Filter Pack (37946C) is not recommended. The Wide Range Filter Pack (37617C) should be used for these applications.

When an invasive kV divider is connected to high-frequency, high-ripple generators for calibration, the kV waveform is often substantially changed due to the capacitance of the added high voltage cables. When the invasive divider is subsequently removed for normal operation of the X-ray system, the kVp at any given generator setting may be significantly higher than was measured with the divider. The Model 35080A kVp Divider with the Mobile Filter Pack (37946C) provides an easy and accurate non-invasive method for measuring the kVp of these systems.

When the Mobile Filter Pack (37946C) option is added to a Model 35080A kVp Divider manufactured before April 1994 (S/N 63194 or lower), a circuit modification is incorporated into the Model 35080A kVp Divider to improve the frequency response. Therefore, retrofitting a Mobile Filter Pack (37946C) to a Model 35080A kVp Divider must be done at the Keithley factory.

8.2 INTRODUCTION *(continued)*

The operating instructions for the Mobile Filter Pack (37946C) are the same as given in Section 4--OPERATING INSTRUCTIONS--for the Wide Range Filter Pack (37617C) with minor exceptions as detailed below. The recommended source-to-detector distance is **12 inches**, rather than the 22 inches suggested for the Wide Range Filter Pack (37617C). The long axis of the Model 35080A kVp Divider should still be perpendicular to the X-ray tube axis to avoid "heel effect", as shown in Figures 4-2 and 4-3.

The formula used to calculate the kV is the same as for the Wide Range pack:

kV = Model 35080A voltage x 100 + ZERO kV

where the ZERO kV is 40 for both the Mobile and Wide Range Filter Packs (37946C and 37167C). However, when the Model 35080A kVp Divider is placed in the "CAL" mode with a Mobile Filter Pack (37946C) inserted, an output voltage of 0.600 V ±1% should be obtained, corresponding to a CAL kV of 100.

The Model 35080A kVp Divider has a special circuit intended to prevent the presentation of a distorted waveform at low intensities. Section 3.5--Intensity Cut-off--discusses the effect of this circuit for single phase waveforms. For generators with substantial kV ripple, for which the Mobile Filter Pack (37946C) is intended, this same effect may be noticed. As the kV waveform decreases, the output suddenly switches to the filter pack's baseline, which corresponds to 40 kVp with the Mobile Filter Pack (37946C). During the rising portion of the next kV cycle, the output will switch back to and follow the actual waveform, as shown in Figure 3-3 for the single phase example. This is normal operation of the Model 35080A kVp Divider for large ripple signals.

The filtration and linearity correction curves for the Mobile Filter Pack (37946C) are given in the next two sections. In Section 8.5--Frequency Corrections, a frequency correction curve is given which can be used to correct kVp measurements obtained on X-ray generators of various frequencies and kV ripple. No correction is required for 2kHz waveforms with 20% observed ripple.

8.3 FILTRATION EFFECT CORRECTIONS

Corrections for filtration are made using the correction curve shown in Figure 8-1. The Mobile Filter Pack (37946C) is calibrated at 2.5 mm Al total filtration, so measurements made at other filtration values require correction of the measured reading. Corrections are made by subtracting the total filtration of the X-ray machine being measured from 2.5 mm Al, multiplying the result by the value read off the chart for the measured kVp, and adding this result to the measured kVp.

Example: The Model 35080A kVp Divider with a Mobile Filter Pack (37946C) inserted reads 80 kVp. The X-ray system has 3.3 mm Al total filtration. The filtration effect curve of Figure 8-1 indicates a filtration effect of 1.05 kVp per mm Al at 80 kVp. The difference in filtration, 2.5 - 3.3 = -0.8 mm Al, is multiplied by the correction value to yield -0.8 x 1.05 = -0.84 kVp. This number is then added to the apparent reading to obtain the actual kVp, which is
80 kVp + (-0.84 kVp) = 79.16 kVp.

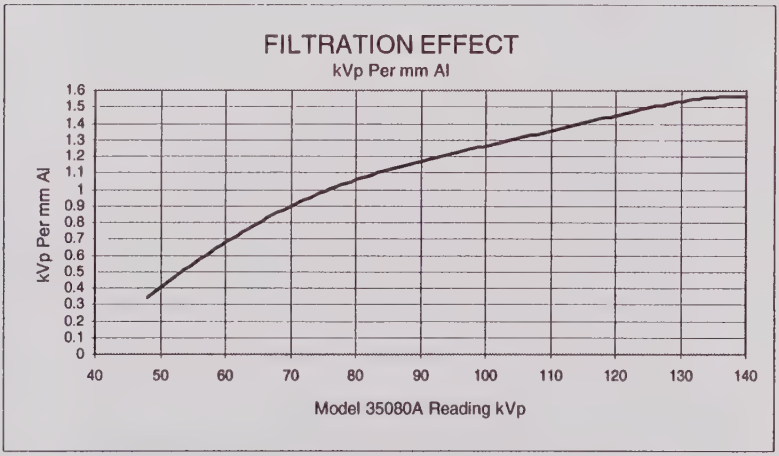

Figure 8-1. Mobile Filter Pack (37946C) Filtration Effect Correction Curve.

8.4 LINEARITY CORRECTIONS

Corrections for linearity of the Mobile Filter Pack (37946C) can be made by taking the measured output of the Model 35080A kVp Divider and adding the value in kVp shown on the curve in Figure 8-2. For best accuracy, filtration corrections should be made prior to the linearity corrections. If the difference in total filtration from the calibration standard of 2.5 mm Al is small, however, linearity corrections alone may be sufficient. See Section 8.3--Filtration Effect Corrections--for information regarding filtration corrections.

Example: The Model 35080A kVp Divider with a Mobile Filter Pack (37946C) has a reading of 90 kVp. From the chart, a kVp Correction value of -0.9 kVp is obtained. Assuming filtration corrections are not required for this X-ray system, the actual kVp is 90 + (-0.9) = 89.1 kVp.

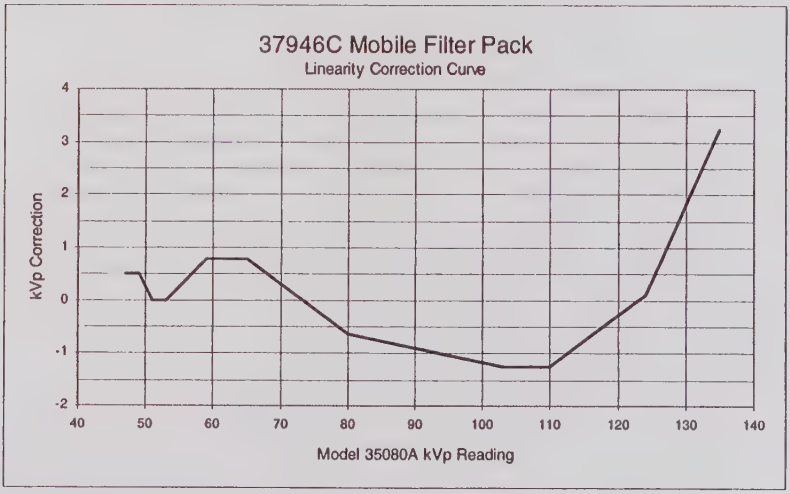

Figure 8-2. Mobile Filter Pack (37946C) Linearity Correction Curve. The kVp Correction Value read from the vertical scale should be added to the Model 35080A kVp Divider reading to obtain the corrected kVp result.

8.5 FREQUENCY CORRECTIONS

The Mobile Filter Pack (37946C) is optimized for measurements on kVp waveforms at 2kHz, and with 20% observed ripple on the output waveform of the Model 35080A kVp Divider. For measurements under these conditions, no frequency correction is necessary. The chart in Figure 8-3 can be used to correct kVp readings obtained on X-ray systems with other frequency or observed ripple values. The horizontal axis is the actual frequency of the kV waveform and the percentages listed for each curve correspond to the observed ripple on the Model 35080A kVp Divider waveform. The correction value read off the vertical axis should be added to the measured kVp to obtain the actual kVp.

Example: The Model 35080A kVp Divider used with a Mobile Filter Pack (37946C) gives a kVp waveform reading of 90 kVp with 10% observed ripple. The waveform also shows a waveform frequency of 4 kHz. From Figure 8-3, a correction value of 1.8 kVp is read from the 10% ripple curve at 4 kHz. Therefore, the actual kVp for this exposure is 90 + 1.8 = 91.8 kVp. It should be noted that for 3-phase generators, or generators with little or no ripple, the correction value is -2 kVp indicating the 2 kVp should be subtracted from readings on these machines.

8.5 FREQUENCY CORRECTIONS *(continued)*

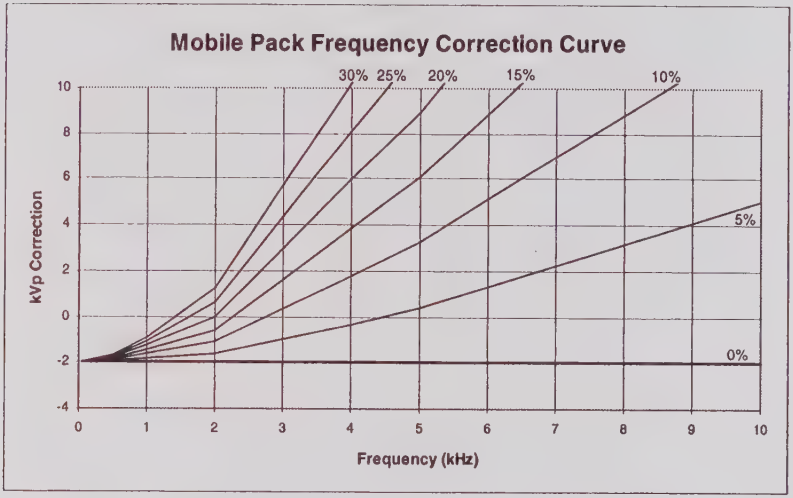

Figure 8-3. Frequency Correction Curves for the Mobile Filter Pack (37946C). The percentages listed for each curve correspond to the observed ripple on the kV waveform from the Model 35080A kVp Divider.

Section 9
MAINTENANCE

9.1 TROUBLESHOOTING

Difficulties experienced by the Model 35080A kVp Divider user may be caused by problems from one or more of the three sources described below: Problems with the storage oscilloscope used to obtain the kV reading; problems with the X-ray machine; and either improper technique or an electronic fault with the Model 35080A kVp Divider. Typically, the existence of a problem would be signalled by one of the following:

1. No waveform on the oscilloscope trace;

2. A strange or unexpected waveform on the oscilloscope trace.

The information given below is provided to direct the user to the most likely sources of minor problems; it is not meant to provide all solutions to all possible problems.

Problems with the oscilloscope:

1. If the oscilloscope settings for CAL and ZERO are not correct, a waveform may not be displayed, or an unusual or unexpected waveform may be observed. Refer to Section 4.4--Oscilloscope Zero and Offsets.

2. The oscilloscope may be grounded or inoperative.

   Check the operation of the oscilloscope.

3. The oscilloscope trigger may be set improperly.

9.1 TROUBLESHOOTING *(continued)*

Problems with the X-ray machine:

1. The X-ray machine may be inoperative.

   Verify with a dosimeter that the X-ray machine is functioning.

2. The X-ray machine may be arcing. Arcing is characterized by erratic spikes superimposed on the kV waveform.

3. The X-ray machine may be badly adjusted.

Problems with the Model 35080A kVp Divider:

1. The power battery may be weak or dead.

   Check the battery and replace it if necessary (see Sections 4.1--Battery Check and 9.2--Battery Replacement).

2. The function switch on the Model 35080A kVp Divider may be in the wrong position, such as "CAL".

   Verify that the function switch is in the "RUN" position.

3. Orientation of the Model 35080A kVp Divider may not be correct for the location of the X-ray source.

   (Refer to Section 4.5--Geometry of Set-up). Turn the Model 35080A kVp Divider upside-down for under-table X-ray heads and right-side-up for above-table X-ray heads.

4. There may be an electronic fault in the Model 35080A kVp Divider.

   Check the CAL operation of the Model 35080A kVp Divider (refer to Section 4.2--Internal Calibration Check).

9.2 BATTERY REPLACEMENT

The Model 35080A kVp Divider is powered by a single 9.0 V Eveready type 522 alkaline battery. Battery life is approximately 60 hours. The charge on the power battery can be checked without opening the instrument case; with the function switch in the "BAT CHK" position, a digital voltmeter (DVM) can be connected across the output terminals (red and black) on the left side of the instrument case.

NOTE

Do not leave the function switch in the "BAT CHK" position, as this will decrease battery life.

If the battery voltage drops below 7.0 V, the battery should be replaced, as the remaining life of the battery is quite limited. If the battery voltage is already below 6.25 volts when checked, the battery must be replaced for proper operation of the Model 35080A kVp Divider.

To replace the battery, remove the screw from the cover on the bottom of the Model 35080A kVp Divider (refer to Figure 9-1). Lift the cover from the instrument case. Place your hand over the battery compartment and roll the instrument upright, letting the battery drop into your hand.

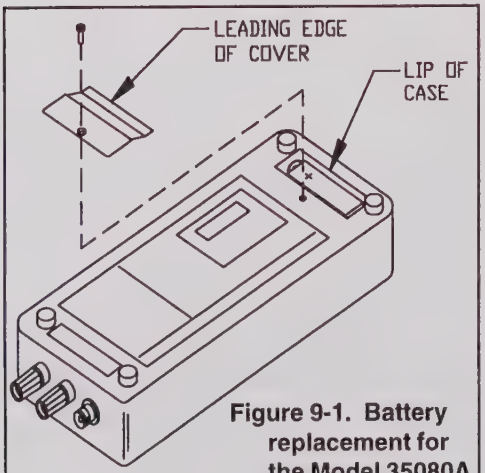

Figure 9-1. Battery replacement for the Model 35080A kVp Divider.

Carefully disconnect the battery terminal from the used battery and replace it with a fresh 9V alkaline battery (Eveready type 522). Slip the battery back into the compartment and replace the cover. Note that the leading edge of the cover must be inserted under the lip of the instrument case before it is properly seated (refer to Figure 9-1). Align the hole in the cover with the threaded hole in the case and reinsert the screw.

9.3 CALIBRATION

WARNING

The factory calibration of the Model 35080A kVp Divider is performed with a precision high-voltage divider and a 12-bit ±0.1% digital oscilloscope. If comparable equipment is not available, do NOT attempt to make adjustments on the Model 35080A kVp Divider. Return the unit to the factory for adjustment.

(Review Section 3--THEORY OF OPERATION.) Calibration of the Model 35080A kVp Divider depends primarily on the stability of the filter pack. Since the filter pack primarily consists of metal sheets, the absorption is not expected to change with time. There are only two calibration adjustments in the Model 35080A kVp Divider. One adjustment (RP103) sets the gain of the ratio circuit. The other adjustment (RP101) sets the ratio of the internal reference currents which are used as an internal calibration check when the function switch is set to the "CAL" mode.

Internal Calibration Check:

1. Set the function switch to the "CAL" position.
2. Insert the Test Pack (32863C).
3. The output voltage should read 0.750 volts ±1%.

NOTE

Each 1% deviation of this value will result in no more than a 0.75% of reading error. This measurement must be made with a ±0.1% DVM.

9.3 CALIBRATION *(continued)*

External Calibration Check:

1. Place the Model 35080A kVp Divider in the "RUN" mode. Insert the Test Pack (32863C).
2. Place the Model 35080A kVp Divider in the X-ray beam as described in Section 4.6--Use of the Test Pack (32863C).
3. With a 100 kV, 200 mA exposure (22 inches source-to-table), the output should be 3 volts ±1%.

NOTE

Most oscilloscopes are not accurate enough (0.1%) to make this measurement. Each 1% of misadjustment will cause a maximum of 0.75% of reading error.

Calibration Adjustment:

NOTE

Only facilities with precision calibration equipment should adjust the calibration of the Model 35080A kVp Divider.

1. Insert the Test Pack (32863C). Place the Model 35080A kVp Divider on the X-ray table, such that the distance from source to table is 22 inches, and the instrument is normal to the beam--with the long axis of the Model 35080A kVp Divider perpendicular to the axis of the X-ray tube; this configuration will avoid "heel effect." Settings on the generator for kVp should be 100 kV and 200 mA.
2. With the Model 35080A kVp Divider in the "OFF" mode, zero the oscilloscope.

9.3 CALIBRATION *(continued)*

3. Turn the mode switch on the Model 35080A kVp Divider to the "RUN" position.

4. Make an X-ray exposure (greater than 1 mS duration for three-phase generating equipment--greater than 1 line cycle duration for single-phase generating equipment).

5. Accurately measure the peak voltage (±0.1%). Record this value as "A".

6. If "A" falls outside of the range 2.970 to 3.030 volts, adjust the Model 35080A kVp Divider, as follows.

7. Remove the Model 35080A kVp Divider instrument case to access the adjustment potentiometers. Place the Model 35080A kVp Divider in the "CAL" mode and measure the output voltage (±0.1% accuracy). Record this value as "B".

8. With the Model 35080A kVp Divider still in the "CAL" mode, adjust RP102 until the output is

$$V = 3.000 \times B / A \text{ volts.}$$

9. With the instrument still in "CAL", adjust RP101 until the output = 0.750 volts.

10. Place the Model 35080A kVp Divider back in its instrument case and turn the function switch to the "RUN" mode. Repeat Step 5. The value should be 3.00 volts ±1%. If not, repeat the sequence.

NOTE

If the oscilloscope in use is not accurate to ±0.1%, do not attempt adjustment of the Model 35080A kVp Divider.

9.3 CALIBRATION *(continued)*

Other Adjustments:

The third adjustment potentiometer (RP103) adjusts the amount of the waveform which is displayed by the oscilloscope. If annoying artifacts are observed on the oscilloscope, turning the potentiometer (RP103) counterclockwise will decrease the width of the waveform displayed on the oscilloscope. Turning the same potentiometer clockwise will conversely increase the width of waveform displayed. Refer to Figure 9-3 for an illustration of the effects of this adjustment.

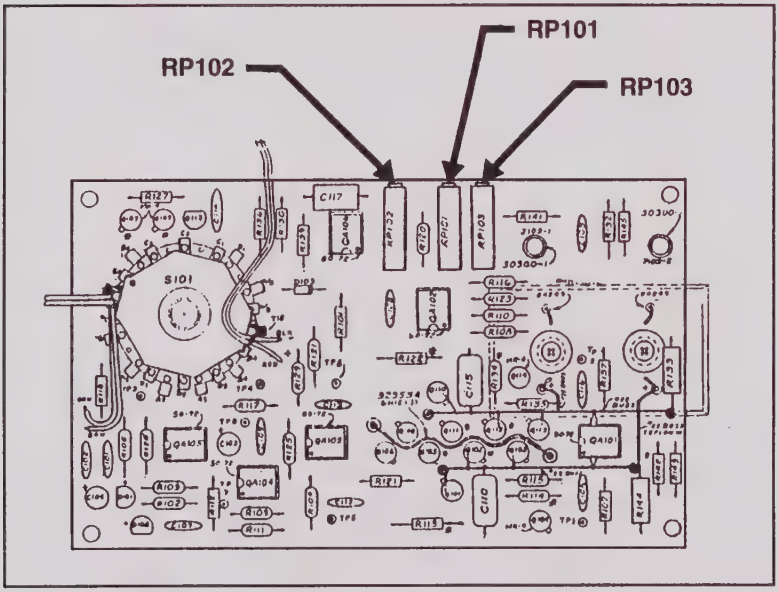

Figure 9-2. Location of RP101, RP102, and RP103.

9.3 CALIBRATION *(continued)*

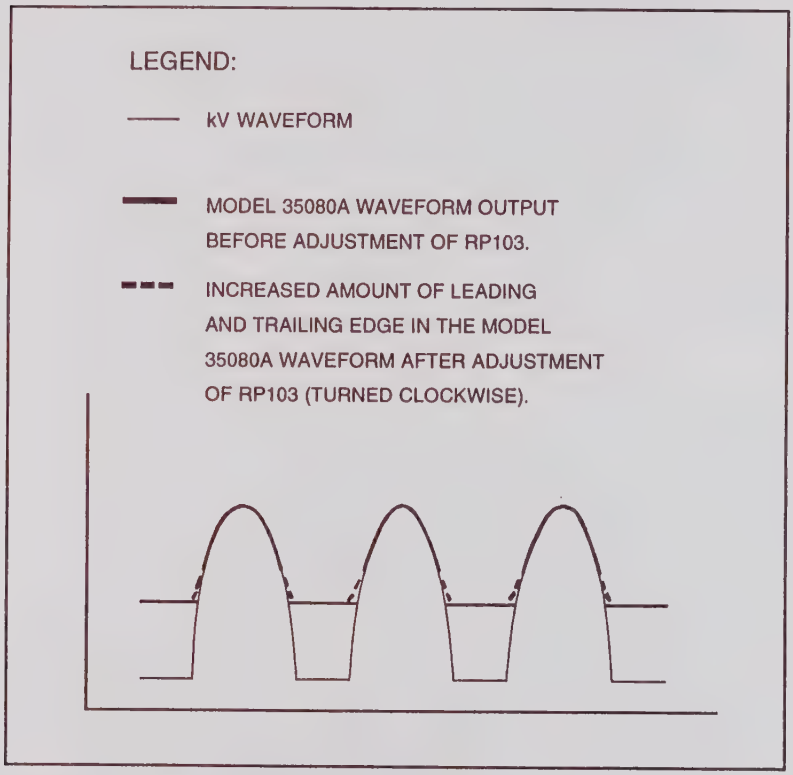
LEGEND:
kV WAVEFORM
MODEL 35080A WAVEFORM OUTPUT BEFORE ADJUSTMENT OF RP103.
INCREASED AMOUNT OF LEADING AND TRAILING EDGE IN THE MODEL 35080A WAVEFORM AFTER ADJUSTMENT OF RP103 (TURNED CLOCKWISE).

Figure 9-3. Effects of RP103 adjustment.

9.4 REPLACEABLE PARTS LIST

Table 9-1. Replaceable Parts List.

Description	Keithley Part Number
Power battery, 9.0 V, alkaline	Eveready 522
Test Pack	32863C
50 - 150 kV Wide Range Filter Pack	37617C
Linear Mammo Filter Pack (Optional)	37351C
Cadmium K-edge Mammo Filter Pack (Optional)	37355C
CT Filter Pack (Optional)	33551C
Mobile Filter Pack (Optional)	37946C
Instruction Manual	37648IM

9.5 PARTS ORDERING INFORMATION

Keithley Instruments, Inc. maintains a complete inventory of all normal replaceable parts. To place an order, or to obtain information concerning replaceable parts, contact you Keithley representative or the factory at (800) 552-1115, (216) 498-2564, or FAX: (216) 349-2307. When phone or mail ordering parts (see next section for shipping address), include the following information.

1. Instrument Model Number
2. Instrument Serial Number
3. Part Description
4. Keithley Part Number
5. Ship-to Address
6. Bill-to Address
7. Telephone Number
8. Contact Person
9. Purchase Order Number

9.6 REPAIR INFORMATION / TECHNICAL ASSISTANCE

We recommend you phone the Keithley Radiation Measurements Repair Coordinator at (800) 552-1115, (216) 498-2564, or FAX: (216) 349-2307, if you instrument needs repair.

When returning your instrument for repair, you must include the following information:

1. A completed service form at the back of this manual
2. A copy of your purchase order requesting the service
3. Ship-to and Bill-to addresses

Ship to:

Radiation Measurements Division
Keithley Instruments Inc.
31300 Bainbridge Road
Cleveland, OH 44139 U.S.A.

More information concerning the operation, application, or service of your instrument may be obtained from the applications engineer at the above office.

9.7 WARRANTY INFORMATION

We warrant our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof which, within one year after shipment, proves defective upon examination.

To exercise this warranty, which is described on the inside of the front cover, write or call your local Keithley representative, or contact Keithley headquarters in Cleveland, Ohio, at (800) 552-1115 or (216) 498-2560. When calling for warranty information, you will be given prompt assistance. When writing, send mail to the following address:

Radiation Measurements Division
Keithley Instruments Inc.
28775 Aurora Road
Cleveland, OH 44139 U.S.A.

NOTE

This warranty does not cover battery replacement or damage caused by battery leakage.

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Appendix A
MAMMOGRAPHIC MEASUREMENTS WITH THE MODEL 35080A kVp DIVIDER

We recommend that the two mammographic filter packs, K-edge Mammo Filter Pack (37355C) and Linear Mammo Filter Pack (37351C) be used together. The K-edge Mammo Filter Pack (37355C) is used first to find a point between 27.5 kV and 29.5 kV very accurately. Then, the Linear Mammo Filter Pack (37351C) measurement is made at the same point to determine the necessary correction to apply to all readings taken with the Linear Mammo Filter Pack (37351C). The K-edge measurement should be performed each time a generator is tested.

Part of the correction factor for the Linear Mammo Filter Pack (37351C) is due to variations in tube filtration and part is due to positional dependence. Therefore, if the Model 35080A non-invasive kVp Divider is moved when using the Linear Mammo Filter Pack (37351C), a new measurement at the K-edge comparison kVp point must be made with the Linear Mammo Filter Pack (37351C) to compute a new correction factor.

The following procedure enables the first-time user to achieve good results. An experienced user can take many short cuts. The Model 35080A kVp Divider with the mammo kVp option is for use on molybdenum anode, beryllium window tubes only.

A.1 K-EDGE MEASUREMENT

Measurement Set-up

1. Remove the cone.
2. Remove the compression paddle, turn it upside down and reinstall as shown in Figure 5-3.
3. Place the Model 35080A kVp Divider (with a K-edge Mammo Filter Pack--37355C) on top of the compression paddle as close as possible to the X-ray tube.
4. Level the Model 35080A kVp Divider.

Oscilloscope Set-up

1. Connect the Model 35080A kVp Divider to the scope using a shielded cable.
2. Set the vertical sensitivity to 0.5 volts per division.
3. With the input in the "GROUND" position, adjust the vertical position control to place the trace on the bottom graticule line.
4. Set the scope in single trace, storage mode.
5. Place the input selector switch in the "DC" position.

K-Edge Measurement Procedure

Part A

1. Set the X-ray generator for 25 kVp, 100 mA--or an mAs setting that provides the maximum tube current--at least 50 mA.
2. Select the Mo (molybdenum) filter.
3. Make an exposure, adjusting the scope trigger level as necessary to get a stable trace.
4. Measure the peak voltage and record in box A on the accompanying data sheet. (Figure A-2.)

K-Edge Measurement Procedure *(continued)*

Part B

1. Set the generator for 26 kVp and make an exposure.
2. Record this voltage value in box B on the data sheet (Figure A-2). (The voltage values, A and B, should be equal to within ±0.020 V; if so, this will be your BASE VOLTAGE; if not, then repeat the above steps, at one kVp lower.)

Part C

1. Set the generator for 29 kVp and make an exposure.
2. Measure the peak voltage. (If this voltage is greater than the BASE VOLTAGE by 0.1 V but not greater than 0.25V above the BASE VOLTAGE, record in box C (Figure A-2). If the voltage is greater than 0.25 volts above the BASE VOLTAGE, repeat this step at one kVp lower. If the voltage is not greater than the BASE VOLTAGE by 0.1 volts, repeat this step at one kVp higher.)

Part D

Repeat the last measurement to verify that the generator is repeatable. The voltage reading should repeat to within 0.020 V. If the reading is not repeatable, the generator needs service.

Part E.

1. Subtract the BASELINE voltage from the voltage measured in Part C, step 2 (box C).
2. Multiply this voltage by 10, add to 27.0, and record in box D (Figure A-2). This is the true kVp for this station.
3. Set the scope for single sweep, storage mode, and in the "DC" input mode.

PROCEED TO LINEAR MEASUREMENT - DO NOT CHANGE THE GENERATOR SETTINGS

A.2 LINEAR MEASUREMENT

Measurement Set-up

1. Replace the Cadmium K-edge Mammo Filter Pack (37355C) with the Linear Mammo Filter Pack (37351C).
2. Reposition the Model 35080 kVp Divider to approximately 15 inches from the focal spot (see Figure 6-3).

Oscilloscope Set-up

1. Set the vertical sensitivity to 0.05 volts per division.
2. With the input switch in the "GROUND" position use the vertical position control to place the trace on the bottom graticule line.
3. Set scope for single sweep, storage mode, and in the "DC" input mode.

Linear Measurement Procedure

Part A

1. With the generator settings used for K-edge measurement in Part C, make an exposure.
2. Record the voltage in box E (Figure A-2), then multiply the voltage in box E by 100 and record as kVp in box F.

Part B

1. Subtract the kVp in box F from the kVp in box D (Figure A-2). (This will be the CORRECTION VALUE applied to all kVp measurements made with the Linear Mammo Filter Pack--37351C.)
2. Insert this value in all spaces in the column labeled "CORRECTION VALUE."

Linear Measurement Procedure *(continued)*

NOTE

This value may be either positive or negative.

Part C

1. Measure other kVp values as desired.
2. Enter the voltage in the "LINEAR VOLTAGE" column on the data sheet; multiply by 100.
3. Enter the value in the "LINEAR kVp" column.
4. Apply the CORRECTION VALUE to all kVp's by either adding to or subtracting from the "LINEAR kVp" column, and record the results in the "CORRECTED kVp" column. (This column now has the true kVp value for all kVp's measured.)

Part D

If the position of the Model 35080A kVp Divider changes during the Linear kVp measurement, you must repeat the measurement starting with Part C: some of the correction value is positional dependent.

Set kVp	K-edge Voltage	True kVp	Linear Voltage	Linear kVp	Correction Value	Corrected kVp
22	———	———	0.213	21.3	+0.8	22.1
23	———	———	0.221	22.1	+0.8	22.9
24	———	———	0.230	23.0	+0.8	23.8
25	(A) 3.10	———	0.237	23.7	+0.8	24.5
26	(B) 3.10	———	0.249	24.9	+0.8	25.7
27	———	———	0.255	25.5	+0.8	26.3
28	———	———	0.267	26.7	+0.8	27.5
29	(C) 3.26	(D) 28.6	(E) 0.278	(F) 27.8	+0.8	28.6
30	———	———	0.287	28.7	+0.8	29.5
31	———	———	0.299	29.9	+0.8	30.7
32	———	———	0.308	30.8	+0.8	31.6
33	———	———	0.319	31.9	+0.8	32.7
34	———	———	0.33	33.0	+0.8	33.8
35	———	———	0.342	34.2	+0.8	35.0
36	———	———	0.351	35.1	+0.8	35.9

Figure A-1. The Model 35080A Mammographic Worksheet (Example).

Set kVp	K-edge Voltage	True kVp	Linear Voltage	Linear kVp	Correction Value	Corrected kVp
22	———	———				
23	———	———				
24	———	———				
25	(A)	———				
26	(B)	———				
27	———	———				
28	———	———				
29	(C)	(D)	(E)	(F)		
30	———	———				
31	———	———				
32	———	———				
33	———	———				
34	———	———				
35	———	———				
36	———	———				

Figure A-2. The Model 35080A kVp Divider Mammographic Worksheet.

Appendix B
CORRECTING kVp MEASUREMENTS FOR GAIN EFFECTS

NOTE

Section 9.3--Calibration--of the Model 35080A kVp Divider user's manual details a method for performing gain corrections by adjusting the internal potentiometers of the instrument. This remains a completely acceptable technique. The purpose of this addendum is to provide an alternative method for users with sealed units, who cannot access the adjustment potentiometers.

B.1 INTRODUCTION

The calibration mode feature of the Model 35080A kVp Divider provides a method to monitor the gain of the internal circuitry. When the Model 35080A kVp Divider is placed in CAL mode, the specific voltage and kVp stated on each individual filter pack should be obtained. If the output voltage in CAL mode is not within ±1% of the value stated on the pack, kVp measurements should be corrected in one of the following ways, depending on the device used for measuring the output of the Model 35080A kVp Divider. A deviation of less than ±1% will result in a maximum kVp error of 0.75% of reading.

B.2 OSCILLOSCOPE MEASUREMENTS

The Model 35080A kVp Divider Instruction Manual describes the technique that should be used to measure kVp when connected to an oscilloscope (Section 4.4--Oscilloscope Zero and Offsets). A slight modification of this technique will allow for the correction of gain effects. Briefly, this technique is as follows.

1. Insert the filter pack to be used into the Model 35080A kVp Divider and connect to the oscilloscope. Set the oscilloscope gain to an appropriate value depending on the sensitivity of the filter pack.

2. With the function switch of the Model 35080A kVp Divider set to OFF, adjust the oscilloscope vertical position such that the trace coincides with the bottom horizontal line on the screen. This line now corresponds to the Zero offset kVp given on the pack.

3. Switch the Model 35080A kVp Divider to the CAL position. The oscilloscope trace should now be at a level corresponding to the CAL kVp given on the filter pack. If this is not the case, the gain effects should be corrected before making kVp measurements in the RUN position.

4. The gain effects can be corrected by adjusting the fine tuning knob on the Volts/div. switch of the oscilloscope. While still in the CAL position, adjust this knob until the trace on the screen corresponds to the kVp value expected for the filter pack in use. Measurements made in RUN mode will now be corrected for gain effects.

B.3 VOLTMETER MEASUREMENTS

If the output of the Model 35080A kVp Divider is connected to a voltmeter, a mathematical correction is required to compensate for gain effects. The first step in this correction process is to determine the expected and actual voltages when the Model 35080A kVp Divider is placed in CAL mode. With the filter pack in place, switch the Model 35080A kVp Divider to the CAL position and read the voltmeter to obtain the actual CAL voltage of the unit. The expected CAL voltage is the value listed on the filter pack itself. If these values do not agree to within ±1%, perform the following correction for all subsequent kVp measurements made using this filter pack.

Voltages obtained in RUN mode will deviate from correct values by the same ratio as the deviation in CAL voltages. That is,

$$\frac{\text{Actual CAL Voltage}}{\text{Expected CAL Voltage}} = \frac{\text{Measured Voltage in RUN mode}}{\text{Corrected Voltage}}$$

where Corrected Voltage is the true voltage that would be obtained if the gain were accurate. Therefore, we can obtain a Corrected Voltage for any exposure by rearranging the above equation.

$$\text{Corrected Voltage} = \text{Measured Voltage}\left(\frac{\text{Expected Voltage in CAL mode}}{\text{Actual Voltage in CAL mode}}\right)$$

The corrected kVp is then calculated as usual by multiplying the Corrected Voltage by the sensitivity and adding the Zero offset kVp of the particular filter pack in use.

B.3 VOLTMETER MEASUREMENTS *(continued)*

Example: A Model 35080A kVp Divider with a Wide Range Filter Pack (37617C) (50 - 150 kVp) is connected to a voltmeter and switched to CAL mode. A value of 0.412 V is observed, which is 3% higher than the expected CAL voltage of 0.400V for this pack. Therefore, subsequent measurements made with this pack should be corrected.

The Model 35080A kVp Divider is now switched to RUN mode. An X-ray exposure is made, and a voltage of 0.515 V is measured. A Corrected Voltage is calculated from the previous equation.

$$\text{Corrected Voltage} = 0.515\text{V}\left(\frac{0.400\text{V}}{0.412}\right) = 0.500\text{V}$$

Using the sensitivity of 0.1V/10kV and 40 kVp Zero offset given for this filter pack, the Corrected kVp is 90. A kVp of 91.5 would have been measured if the above gain correction had not been performed.

B.4 THE MODEL 35050A DOSIMETER MEASUREMENTS

The Model 35050A Dosimeter/kVp Readout automatically converts the output voltage of the Model 35080A kVp Divider to a kVp value, using the sensitivity and Zero kVp offset of the selected filter pack. Therefore, the method for calculating a Corrected kVp value is slightly different.

B.4 THE MODEL 35050A DOSIMETER MEASUREMENTS

(continued)

The first step again is to determine the actual and expected values with the Model 35080A kVp Divider in CAL mode. In this case, since the values are in kVp rather than raw voltages, the Zero offset value must be included in the calculation. The ratio equation in terms of kVp values is:

$$\frac{(\text{Actual CAL kVp} - \text{Zero offset kVp})}{(\text{Expected CAL kVp} - \text{Zero offset kVp})} = \frac{(\text{Measured kVp in RUN mode} - \text{Zero offset kVp})}{(\text{Corrected kVp} - \text{Zero offset kVp})}$$

where the Expected CAL kVp and Zero offset kVp correspond to the values given on the actual filter pack. Note that the sensitivity need not be considered since it cancels out of the above equation. The Corrected kVp can be obtained directly from this equation by rearranging.

$$\text{Corrected kVp} = (\text{Measured kVp} - \text{Zero offset})\left(\frac{\text{Expected CAL kVp} - \text{Zero offset}}{\text{Actual CAL kVp} - \text{Zero offset}}\right) + \text{Zero offset}$$

Example: For the Wide Range Filter Pack (37617C) (50 - 150 kVp), the Expected CAL kVp is given as 80, and the Zero offset value is 40 kVp. However, a Model 35080A kVp Divider in CAL mode with this filter pack inserted is connected to a Model 35050A Dosimeter, and a kVp of 81.2 is measured. When placed in an X-ray beam in RUN mode, the Model 35050A Dosimeter reads 91.5 kVp. The Corrected kVp for this exposure is calculated from the previous equation.

$$\text{Corrected kVp} = (91.5\text{ kVp} - 40\text{ kVp})\left(\frac{80\text{ kVp} - 40\text{ kVp}}{81.2\text{ kVp} - 40\text{ kVp}}\right) + 40\text{ kVp} = 90\text{ kVp}$$

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KEITHLEY RADIATION MEASUREMENTS

SERVICE FORM

Model No. _____ **Serial No.** _____

P.O.No. _____ **Date** _____

***Phone** _____

***Name** _____

Company _____

Address _____

City _____ **State** _____ **Zip** _____

List all control settings and describe problem. _____

_____

(Attach additional sheets as necessary.)

Show a block diagram of your measurement system.

*Be sure to include your name and phone number on this service form.

SERVICE FORM *(continued)*

Where is the measurement being performed? (factory, controlled laboratory, out-of-doors, etc.) _____

What is the ambient temperature? _____ °F.

Temperature Variation? _____ °F.

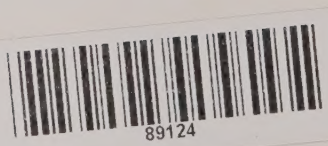
Relative Humidity? _____

Other? _____

Any additional information. (If special modifications have been made by the user, please describe below.)

_____

_____



KEITHLEY RADIATION MEASUREMENTS

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